Renewable and Sustainable Energy Reviews 15 (2011) 1057–1066

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Energy poverty: A special focus on energy poverty in India and renewable energy technologies

Anjali Bhide, Carlos Rodríguez Monroy *

Department of Business Administration, School of Industrial Engineering, Technical University of Madrid, José Gutierrez Abascal, 2, 28006 Madrid, Spain

ARTICLE INFO

Article history:
Received 8 September 2010
Accepted 16 November 2010

Keywords:
India
Energy poverty
Renewable energies
Government subsidies
Energy policy

ABSTRACT

As a large percentage of the world's poor come from India, development in India is a key issue. After the establishment of how access to energy enhances development and the achievement of the millennium development goals, energy poverty has become a major issue. In India there is a great interest in addressing the subject of energy poverty, in order to reach development goals set by the Government. This will imply an increase in India's energy needs. In a climate of change and environmental consciousness, sustainable alternatives must be considered to address these issues.

Renewable energy technologies could provide a solution to this problem. The Government of India has been focussing in implementing electricity policies as well as on promoting renewable energy technologies. The focus of this article is to bring to light the problems faced in India in terms of energy consumption as well as the hindrances faced by renewable-based electrification networks. Government policies aimed at addressing these issues, as well as the current state of renewable energy technologies in India are discussed, so as to analyse the possibility of a solution to the problems of finding a sustainable method to eradicate energy poverty in India. The research reveals that the Government of India has been unable to meet some of its unrealistic development goals, and in order to achieve the remaining goals it will have to take drastic steps. The Government will have to be more aggressive in the promotion of renewable energy technologies in order to achieve sustainable development in India.

Contents

* Corresponding author. Tel.: +34 91 336 4265; fax: +34 91 336 3005.
E-mail address: crmonroy@etsii.upm.es (C.R. Monroy).

1364-0321/$ – see front matter
doi:10.1016/j.rser.2010.11.044

1. Introduction

1.1. Energy and poverty

As per the Human Development Report (1997) [1], the definition of human poverty is seen more as the denial of choices and opportunities for living a tolerable life, than just the traditional definition of income poverty. Even though energy is not sufficient to bring about the required economic and social development to provide these choices and opportunities, it is essential.

The link between energy and poverty has become apparent over the past few decades. According to the IEA analysis [2], around 1.5 billion people, i.e. a quarter of the world population, have no access to electricity. It predicts that in the absence of vigorous new policies, 1.3 billion people will still lack access to electricity in 2030.

The Millennium Development goals set by the UN [3] provide concrete, time-bound objectives for dramatically reducing poverty in its many dimensions by 2015—income poverty, hunger, disease, exclusion, and lack of infrastructure and shelter—while promoting gender equality, education, health, and environmental sustainability. Some of these goals include:

1. Eradication of extreme poverty and hunger.
2. Achievement of universal primary education.
3. Promotion of gender equality and empowerment of women.
4. Reduction of child mortality.
5. Improvement of maternal health.
6. Combating HIV/AIDS, malaria and other major diseases.
7. Ensuring environmental sustainability.

Access to energy enables the achievement of the Millennium Development Goals [3]. Electricity provides lighting and permits usage of household appliances. This extends the number of working hours beyond daylight and enables studying and learning beyond daylight. Modern fuels or electricity can reduce the exposure to indoor pollution, and the time spent in cooking inefficiently and in the collection of firewood. With refrigeration, food can be stored for longer periods of time. Opportunities for self-employment from home grow with access to machinery such as sewing machines. Electricity aids in drawing of water through pumps as well as its purification. With access to electricity, schools can have better hygiene and facilities to attract students. With electricity, clinics can be equipped with modern equipment, carry out proper sterilization of instruments and store various medicines and syringes, thereby improving health services to the people.

It is said [2] that 2.4 billion people rely on traditional biomass, such as wood, agricultural residues and dung, for cooking and heating. This number is estimated to increase to 2.6 billion in 2030. Biomass exposes women and children to indoor pollution everyday. The World Health Organization estimates that 2.5 million women and young children in developing countries die prematurely each year from breathing in the fumes of biomass stoves.

Electricity does not directly replace biomass. The transition from traditional fuels to modern fuels is not straight. The three main determinants in the transition are availability, affordability and cultural preferences. Even if modern fuels can be afforded, people continue to use biomass if the modern fuels are much more expensive than the biomass which is readily available and perceived as "free" (Fig. 1).

Lower income households prefer to use biomass for cooking and heating. As income increases it is seen that electricity and modern fuels are used for lighting, modern appliances, pumps and communication, but they do not substitute cooking and heating. Only in higher income groups is biomass completely substituted in household consumption.

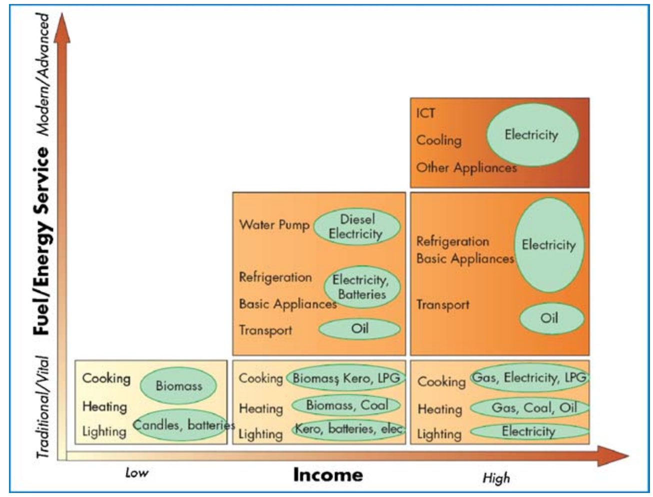


Fig. 1. Household fuel transition.
Source: IEA Analysis World Energy Outlook [2].

1.2. India and energy poverty

India has a population of 1.1 billion, and about 22% [4] of this population lives in poverty. Around 70% of the poor live in rural areas. It has a fast growing population at an annual growth rate of 1.38%. The target set for poverty reduction in India is 19% population below the poverty line by 2015 [5]. The India Planning commission is expecting to meet this poverty target by 2015. The Indian Government has announced plans to provide electricity to the entire population by 2012 to achieve social development [6–8].

According to the World Coal Institute [9], India is the sixth largest electricity generating country as well as the sixth largest electricity consumer. Despite this, the electrification rate is only 44%. The population estimated to have no access to electricity is 582.6 million. Some 140,000 Indian villages out of 586,000 remain to be electrified and in many of the officially electrified ones, quality of service is such that they do not resemble true electrification. About 625 million people do not have access to modern cooking fuels and traditional fuels still provide 80–90% of the rural energy needs.

Detailed statistical research [2] has revealed that in developing countries around 2.4 billion people rely on biomass for cooking and heating, and 1.6 billion people use no electricity at all. Most of these people are from South Asia and sub-Saharan Africa. The health burden as a result of the heavy dependence on biomass and the related indoor pollution is a loss of 1.6–2.0 billion days of work lost annually. The average time spent per month per household in collection of fuel wood is 40.8 h. These factors severely affect women and children who are the ones who bear this burden the most.

India's human development targets were outlined by the Tenth Five Year Plan [5]. The goals have been stated as follows:

1. Reduce poverty by 15 percentage points by 2012.
2. Provide gainful and high-quality employment to the labour force.
3. Provide education to all children by 2003 and have all children complete 5 years of schooling by 2007.
4. Reduce gender gaps in literacy and wage rates by 50% by 2007.
5. Raise the literacy rate to 75% within the 10th Plan.
6. Reduce the decadal rate of population growth between 2001–2011 to 16.2%.
7. Reduce infant mortality rate (IMR) to 45 per 1000 live births by 2007.

8. Reduce the Maternal Mortality Ratio (MMR) to 2 per 1000 live births by 2007 and to 1 by 2012.
9. Increase the forest and tree cover to 25% by 2007 and 33% by 2007.
10. Provide sustained access to potable drinking water by 2007 to all villages.
11. Provide electricity for all by 2012.
12. Clean all major polluted rivers by 2007 and other notified stretches by 2012.

Other than the goals to reduce poverty ratio, reduce gender gaps, increase forest and tree cover, provide electricity to all and to clean all of the major polluted rivers, the other goals set have been more ambitious than those of the millennium development goals. Each of these goals have an energy cost associated with them.

In the course of this article we aim to look at the current energy poverty scenario in India and how the issues can be addressed by renewable energy technologies. We will then look at studies performed on the household consumption patterns in India in order to identify the consumption trends and establish how rural areas need more attention. As energy poverty is more of a problem in rural areas, this article will focus on rural energy poverty. We first look at the current energy scenario in India to get an idea of how electricity is currently being produced and then at renewable technologies in India and their current status. This will give us an idea as to how energy production is taking place and what role renewable energy technologies currently play. We will then consider issues with renewable based rural electrification systems in order to see what hindrances exist and then we will focus on policies established by the government in order to understand how they plan to approach these problems. Existing facts on the current energy scenario in India and on the available renewable technologies in India will also be presented so as to get a picture of how renewable technologies can play a role in eradicating energy poverty in rural areas. By observing all these we aim to establish how development in India can be enhanced by the use of clean energy technologies.

2. Household energy consumption in India

India is a country in energy transition. Through the study of the consumption patterns, a shift from inefficient solid fuels to more efficient liquid and gaseous fuels and electric power has been observed [10]. According to the studies, currently in India, only approximately 8% of residential energy needs are met by the grid, while around 80% of the residential energy is met by the use of solid fuels, such as biomass and coal. The remaining fraction represents the use of liquid fuels in the residential energy mix.

Data collected by the National Sample Survey Office (NSSO) [10] shows that, despite the decline in biomass consumption over the past few decades, even today biomass comprises about 32% of India's primary energy consumption. From 1980–1981 to the period of 2000–2001, the share of biomass consumed by households has decreased from over 90% to a little over 80%. However, looking at the overall biomass consumption, it is observed that this has increased continuously.

In Fig. 2 which compares rural and urban energy consumption, one can see how the rural consumption patterns have not undergone any significant transition, whereas, the urban consumption has been marked by rapid substitution of traditional fuels. It can be seen that rural residential energy consumption still depends on biomass to a large extent. The urban household energy mix on the other hand, is increasingly dominated by commercial fossil-based energy sources and consumption of electricity. Even with this change however, the presence of biomass still continues even in urban households.

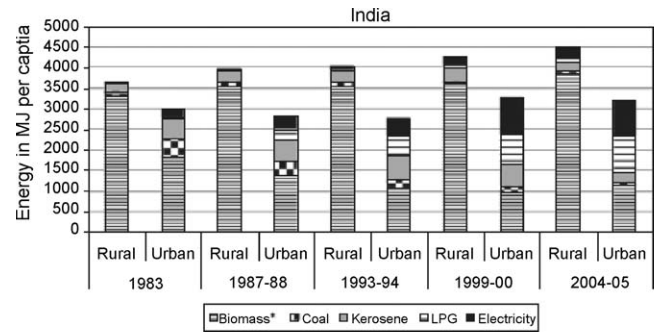


Fig. 2. Per capita energy consumption patterns in urban and rural households. *Source*: Household consumer expenditure surveys [10].

The overall energy trend is characterised by an increase in per capita electricity usage, but this is attributed mainly to the consumption in urban households, as the proportions of commercial energy used in rural households is still low. Also, even though the gas, oil and electricity consumption has risen in rural areas, it is still much lower in aggregate and per capita terms, as compared to urban households.

It is observed that the total residential energy consumption in rural households always exceeds that of the urban households. The cause of this is attributed to the increasing dependence on inefficient solid fuels in the rural areas, while the urban areas switch to more efficient fuel sources.

The study of the use of different sources of household energy, in terms of percentage of population using them in rural and urban households, also gives insight as to what the trends are and how they differ between the two cases. From the table on percentage of population using different sources of household energy, it can be observed that the consumption of various fuel sources in rural or urban households do not add up to a 100%. This reflects how in each household a mix of different energy sources is consumed (Tables 1 and 2).

In rural consumption, the most dominant fuel sources are kerosene, fuel wood and dung. The dependence on coal/coke, kerosene, fuel wood and dung does not seem to vary significantly in the rural areas, while we see the use of sources such as LPG and electricity rise. In the case of urban households however, a significant halving of dependence on biomass sources is observed. Urban households have also shown a shift in transition towards greater dependence on LPG and electricity and lesser on biomass, coal/coke and kerosene.

It is observed [10] that as rural expenditure rises, the consumption of all types of energy sources also rises, without any bias. Only consumers in the top decile in rural areas, show a preference for substitution of solid fuels by non-solid energy forms. In modern households though, the transition to cleaner modern commercial fuels is more apparent with increase in household expenditure. The share of biomass used decreases from 65% amongst the poorest decile to 5% for the richest decile. The top decile exhibits a clear shift away from biomass towards more electricity and LPG use. Kerosene and coal are observed to be transition fuels as in the lower urban deciles the dependence on them increases, whereas in the upper urban decile the dependence decreases. In urban households the energy consumption in the urban middle income decile has a mix of energy types, including more efficient modern fuel is established to produce useful energy.

For the same levels of expenditure in rural and urban areas, the household energy consumption mix differs, with the urban household mix containing more modern fuels and services. As urban areas have higher population density and due to the restrictions in space for fuel storage and collection, a need for delivery of higher den-

Table 1
Percentage of population using different sources of household energy.

	1983		1987–88		1993–94		1999–00		2004–05	
	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban
LPG	0	9	1	20	2	33	6	47	12	61
Coal/coke	3	21	3	14	2	8	2	5	2	5
Electricity	15	58	24	67	36	77	47	84	54	91
Kerosene	95	92	96	88	95	83	96	75	91	55
Fuelwood	86	61	89	50	88	42	88	35	88	35
Dung	53	27	56	24	53	18	52	12	46	10

Source: Household consumer expenditure surveys, [10].

Table 2
Renewable energy sources with their estimated potential and the present number of installations or total capacities.

Source/system	Estimated potential	Cumulative installed capacity/number*
Wind power	45,000 MW	3595 MW
Biomass power	16,000 MW	302.53 MW
Bagasse cogeneration	3500 MW	447.00 MW
Small hydro (up to 25 MW)	15,000 MW	1705.63 MW
Waste to energy		
Municipal solid waste	1700 MW	17 MW
Industrial waste	1000 MW	29.50 MW
Family-size biogas plants	12 million	3.71 million
Improved chulhas	120 million	35.20 million
Solar stieet lighting systems	–	54,795
Home lighting systems	–	342,607
Solar lanterns	–	560,295
Solar photovoltaic power plants	–	1566 kWp
Solar water heating systems	140 million m^2 of collector area	1 million m^2 of collector area
Box-type solar cookers	–	575,000
Solar photovoltaic pumps	–	6818
Wind pumps	–	1087
Biomass gasifiers	–	66.35 MW

Source: Government of India. Ministry of Non-Conventional Energy Sources, [6].
* Number of devices shown which applies when capacity is not expressed in MW or kWp.

sity fuel and electricity exists. Also, it is easier to provide services such as electricity and fuel supply in urban areas at a lower cost, as compared to rural areas which are remote and have a population of lower density and lower purchasing power. In fact, the quality of energy services, such as electricity, is poorer in rural areas, as compared to urban areas. All these factors hamper the availability of different modern fuels in rural areas and decrease the possibility of enhancing rural access to modern energy services.

The fuel choices due to affordability and availability are also reflected in India on a state level. States in India such as Maharashtra, Delhi and Gujarat, where urbanization and income levels are higher, use a larger portion of commercial fuels and electricity as compared to less developed and poorer states in India. Geography and resource endowments in a state determine the fuel choices in that state to a large extent as well. Availability of coal due to mining activities in a state, such as Bihar and West Bengal, leads to a greater dependence on coal as a fuel source as does the availability of hydro based electricity in the states with rivers and suitable terrain, such as the north-eastern states of India.

As fuel choices are also determined by personal choices, demographic factors such as sex and education of the head of the household or decision maker, determine the fuel mix used in households. As women and children are usually the most exposed to indoor pollution, women tend to support the substitution of biomass fuel sources. However, the head of the family and decision maker is usually male in India, and hence this consideration of exposure to indoor pollution is usually overlooked in the purchase of fuel. A lack of education and knowledge of the benefits and adverse effects of different fuels also leads to an uninformed selection of fuel. It is observed [10] that as the educational level of households improves a shift to the use of more efficient fuels is observed.

3. Current energy scenario in India

According to the World Coal Institute [9], India is currently the world's eleventh largest energy producer and accounts for approximately 2.4% of the world's total annual energy production. It accounts for around 3.7% of the world's total annual energy consumption which places it as the 6th largest energy consumer. India is also the 6th largest electricity generator, accounting for almost 4% of the global annual generation, as well as the 6th in terms of electricity consumption.

India's electricity production relies heavily on coal energy sources. A strong second, as can be seen from Fig. 3, is hydro power and the third is natural gas.

Including large scale hydro projects, about one third of the total energy consumed is contributed by renewable energy technologies. Coal currently provides 69% of the electricity demand in India and will continue to be a major source in the future. India has around 10% of the world's coal reserves but this coal is of low quality. This poor quality coal is an inefficient source and highly polluting. Growing concerns for the environment have also driven the need to find substitutes for this energy source.

To meet the growing demand, energy imports such as oil and natural gas have been increasing and energy security and less dependence on imports has become a critical factor to consider. As energy is crucial in terms of development, the Ministry of Power has targeted rural electrification of 100,000 villages by 2012. The Indian Government has announced plans to provide power to the entire population by 2012—this would require an additional 68,500 MW of base capacity.

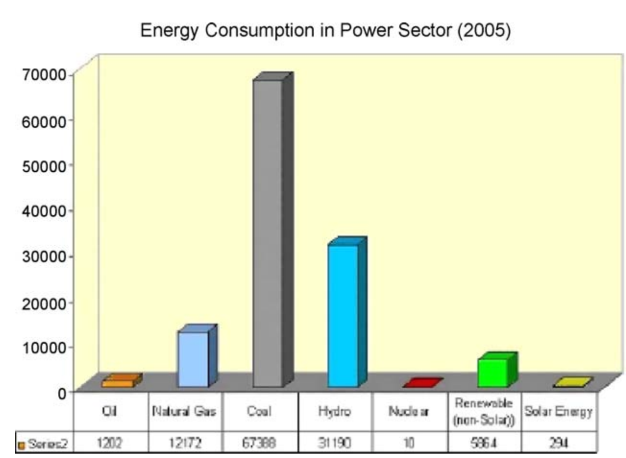


Fig. 3. Energy consumption in Indian power sector in 2005.
Source: GENI (Global Energy Network Institute).

It is observed [10] that the effective price per unit of useful energy being paid by the rural population is significantly higher than that paid by urban residents, as rural households use a higher share of inefficient traditional fuels. By accounting for all fuels and electricity used, they discover that rural households in 1999–2000 spent a higher portion of their total household budget on energy, as compared to urban households.

India has highly subsidised energy for the household sector. It has undergone attempts at liberalisation and price reforms in the past, but a large part of the supply still remains state controlled. The subsidies delivered in India do not vary across rural and urban households, despite the fact that on an average, rural incomes and expenditures are significantly lower than that of urban households.

4. Renewable energy technologies in India

India is rich in renewable energy resources whose potential has not been properly tapped. It has one of the largest programs in the world for deploying renewable energy products and systems. The Government of India has in fact, set up an exclusive ministry for renewable energy development, the Ministry of New and Renewable Energy, the first and only such ministry in the world.

The main sources of renewable energy in India are biomass, biogas, solar, wind and hydro power. Renewable sources contribute about 5% of the total power production in India. India is also the world's highest biogas user and is fifth in the world in terms of both wind power as well as photovoltaic production. From the table on estimated potentials and cumulative installed capacity, it can be seen that none of the potentials of the various renewable sources has been reached.

Renewable based rural electrification systems are being considered as cleaner and environment friendly alternatives to the traditional fuel based systems. In developing countries, these systems are looking at electrifying non-electrified regions, in order to enhance development. These systems are suitable for remote areas and help in providing access to electricity while keeping emissions in check. There are several issues related to these systems.

5. Issues related to renewable based rural electrification systems in developing countries

Studies have been conducted on the issues related to rural electrification using renewable energy in developing countries [11,12]. Here, only those issues which pertain to India will be discussed. The issues related to renewable based rural electrification are mainly categorized as economic, legal and regulatory, and financial and institutional.

The lack of subsidies, high initial capital costs and high transaction costs for small decentralized system are some of the identified economic barriers. Rural electrification programmes involving renewable energy technologies usually involve consumers who have low-incomes, who cannot afford to pay for technologies with high initial capital costs by themselves. A lack of subsidies, financing and credit especially affects these users, rendering these technologies as unaffordable and infeasible to them. In rural areas, the consumers are also scattered over large areas and therefore the additional expense of distribution networks and the high transaction costs for small decentralized systems add to the burden. The demand and use of electricity in rural areas is also low and this makes it less profitable for private companies to offer their services. Failure to incorporate fuel cost risks for fossil fuels and the lack of pricing policies that do not take into account the real economic costs of environmental damage also do not promote a shift to cleaner renewable energy based electrification. The gradual extension of grid networks to rural areas also hampers the development of renewable systems in rural areas.

Identified legal and regulatory barriers to renewable based rural electrification programmes consist of inadequate legal and policy frameworks for renewable energy power sources, and burdensome requirements of the small power producer which are set by their use. Without adequate legal frameworks in place, private companies are normally reluctant and unable to participate in the programmes. A policy framework on the other hand enables the encouragement of the implementation of the technology and provides incentives for private companies, users and other involved parties. The improper use of subsidies prevents the subsidies from effectively targeting the desired results and also slows down the progress in the programmes. Donor dependency in such programmes hampers the development as when there are restrictions in the funding from the donors, the programme comes to a standstill. Unrealistic and political commitments are also identified as barriers. Unrealistic commitments by governments do not motivate the programme implementers in achieving the goals as they know the set goals are too unrealistic, and in fact de-motivate them. Governments of developing countries are known to make commitments based on political interest and these interfere with systematic development of such programmes as the electrification plans can be altered by the politicians at any time according to their interests.

The identified financial and institutional barriers involve the lack of access to credit for both consumers and investors, and the lack of sufficient technical, geographical, and/or commercial information. A reliable and stable line of credit must be available to both consumers and investors in order to promote the set up and the use of these systems despite their high initial capital cost. A lack of information makes the set up of these systems more onerous, and it decreases the attractiveness of investment in them as the market participants are unable to make sound calculated economic decisions. A lack in institutional capacity and technical knowledge prevents provision of guidance and support during the set up and promotion of such systems. Also, the problems related to such programmes require decentralized problem solving and such institutional support is essential.

6. Policies related to electricity in India

In this section the policies that are being put in place in India and how these policies are oriented towards renewable energy technologies, are mentioned. We look at the National Electricity Policy of 2005 and the Electricity Act of 2003 [6].

6.1. National Electricity Policy 2005

Some of the relevant objectives of the National Electricity Policy (2005) are:

- Access to electricity: availability for all the households in the next 5 years (2010).
- Availability of Power: demand to be fully met by 2012. Energy and peaking shortages to be overcome and spinning reserve to be available.
- Supply of reliable and quality power of specified standards in an efficient manner at reasonable rates.
- Per capita availability of electricity to be increased to over 1000 kWh/capita by 2012.
- Minimum lifeline consumption of 1 kWh/household/day as a merit good by 2012.
- Financial turnaround and commercial viability of electricity sector.
- Protection of consumers' interests.

6.2. The Electricity Act 2003

Some of the salient features of the Electricity Act (2003) are:

- Regular preparation and publication of the National Electricity Policy and Tariff Policy.
- Preparation and notification of a national policy, permitting stand-alone systems (including renewable based systems) for rural areas.
- Terms and conditions of determination of tariff to be guided by the promotion of co-generation and generation of electricity from renewable sources and the National Electricity Policy and Tariff Policy.
- State commissions will discharge the functions of:
  - Promotion of cogeneration and generation of electricity from renewable sources by providing suitable measures for connectivity with the grid and sale of electricity to any person.
  - Specification of a percentage of the total consumption of electricity in the area of a distribution license, for purchase of electricity from such sources.

These policies address some of the issues with renewable based rural electrification while also pointing out what the Government is focussing upon. This will be analysed later on. Various renewable energy sources and the technologies associated with them as well as their roles in electrification will now be discussed. Only rural electrification as well as household applications which are useful for rural households and livelihoods will be discussed, as the energy poor are mainly concentrated in the rural parts of India.

6.3. Solar energy

The current solar based installed electrical capacity is approximately 1.4% of the total [6]. Most parts of India receive 4–7 kWh of solar radiation per square meter per day with 250–300 sunny days in a year (Government of India n.d.) [6,13]. Solar energy intensity varies geographically with Western Rajasthan receiving the highest annual radiation energy and the north-eastern regions receiving the least.

Solar Energy can be used through the thermal route or the photovoltaic route. A few applications of the thermal route are water heating, cooking, drying, water purification and power generation. Through the photovoltaic route it can be used for applications such as lighting, pumping, communications and electrification of villages.

There are several applications with respect to solar. Cooking is one such application of solar thermal energy. Solar cookers have no recurring fuel expense and are estimated to save three or four LPG cylinders per year on regular use. As they do not pollute the environment, exposure to indoor pollution by biomass is reduced with their use [14]. Solar cookers cook slowly and hence produce better and more nutritious food, which is a concern to households with low income and scarce meals. Box solar cookers are usually the most suitable for small individual households. The cost of a box solar cooker varies from around $24 to about $51 [6]. Bigger and more expensive community solar cookers are available, which could be useful in schools to provide the students with healthy and nutritious food in order to encourage attendance and prevent them from falling ill. The Indian Ministry of Non-Conventional Energy Sources provides financial support to larger types of solar cookers but not to box solar cookers.

Agriculture involves various time consuming stages in processing, and drying is one of them. Drying in the open sun is not only time consuming but also unhygienic. Solar dryers can be used to dry crops and other products. They come in a variety of types and sizes, and therefore they can be utilized for various domestic purposes as well as in agricultural processes. The disadvantages of these systems is that they are slower than the dryers using conventional fuels and that they can be used for drying only at 40–50 °C [6]. The Ministry of Non-Conventional Energy Sources is implementing a national programme on solar thermal energy, which provides interest subsidy in the form of soft loans as these systems are quite capital intensive. The manufacture of specific purposes and sizes as per requirement is restricted in India and hence large systems have to be set up on project-by-project basis.

Currently, there are 14 photovoltaic companies that manufacture photovoltaic modules, and 45 companies that manufacture solar photovoltaic systems [6]. The Bureau of Indian standards have established photovoltaic standards and the Ministry of Non-Conventional Energy Sources (MNES), has established facilities for testing of solar cells, PV modules, and systems.

Solar photovoltaic lighting systems are becoming popular in rural areas of India. They are used in the form of portable lanterns, home-lighting systems with one or more fixed lamps, and street lighting systems. Solar lanterns are light and portable, normally designed to provide light for 3–4 h of light daily. This aids in providing light in huts beyond daylight hours. They normally cost around $62–$68 depending on their capacities [6].

Solar Home Systems (SHS) provide comfortable levels of illumination in the rooms of a house. Various models of SHS feature one, two or four compact fluorescent lamps. Small DC fans or 12-V televisions can also be run by the system. These systems are designed to work for 3–4 h daily, with an autonomy of three days, which means that they can function for three cloudy days. Different SHS models differ in cost depending on the number of compact fluorescent lamps, fans or televisions they can run. They range from a model which can operate one 9 W compact fluorescent lamp at $124 to a model which can operate four 9 W compact fluorescent lamps at. Solar lighting systems are used to illuminate a street or open areas in villages. These are designed to operate from dusk to dawn automatically. The cost of these systems is about $39 [6]. The Ministry of provides financial assistance for the promotion of these, among eligible categories of users.

Solar photovoltaic (SPV) power plants generate electricity centrally and make electricity available to users through a local grid, stand-alone mode, or connect to the conventional power grid in a grid-interactive mode. Power plants are preferred over the individual SPV systems, when the users are in close proximity. Stand-alone SPV power plants are usually implemented where conventional grid supply is not available, or is erratic and irregular. They are used mostly to electrify remote villages. Their capacity varies from 1 kW_p to 25 kW_p [6], and can even be higher depending on the use. They provide constant, stable and reliable supply to their customers. These systems can also operate where grid supply is available, and the power plant works as a hybrid power plant. The cost of such a power plant depends on the capacity it is built for. The approximate cost is between $6200–$6800/kW of photovoltaic capacity. The distribution costs are not included and would add to these estimates.

For an agricultural based country and in a geographic region where sufficient drinking water is unavailable to a significant population, such as India, solar photovoltaic pumping systems are another important application of photovoltaic energy. These pumps can be used to draw drinking water, as well as water for irrigation. The cost of these pumps depends on the capacity and the type of pump as well.

6.4. Wind power

The most important application of wind energy is the generation of electricity. With 2980 MW of installed wind power capacity, India currently ranks fifth in the world in terms of wind power

capacity. India's current technical potential is estimated at about 13,000 MW, assuming 20% grid penetration [6,13]. However, wind power potential has been assessed at 45,000 MW. A Wind Power Programme was initiated during the Sixth plan, in 1983–84, in order to survey and assess wind resources, set up demonstration projects and to provide incentives, to make wind electricity competitive [6].

As wind power density is not uniform, only certain states have this resource while others do not have sufficient. The windiest states are Gujarat, Andhra Pradesh, Karnataka, Madhya Pradesh and Rajasthan. In fact, the Centre for Wind Energy Technology has set up a Wind Resource Assessment Programme, to tap suitable resources, and has even published wind data they have generated in order to promote wind power. They have even set up master plans to provide information on the availability of wind, land, grid availability and accessibility to the site for the benefit of project promoters.

Several promotional incentives have been made available for wind power projects. The incentives available are 80% accelerated depreciation in the first year and concessional import duty of 5% on five specified wind turbine components, and their parts. Favourable tariffs and policies are also available in several states. These are aimed at promotion of wind power projects by private investors. India also produces wind turbines, mainly through joint ventures or under licensed production agreements.

For decentralized mode rural applications such as pumping and power requirements, wind energy can be harnessed through water-pumping windmills, aerogenerators and wind–solar hybrid systems. Water pumping windmills can be used to pump drinking water and water for minor irrigation, from wells, ponds and bore wells. They do not need high wind speeds and can start lifting water when the wind speed approaches 8–10 km/h, and it has the capacity to pump around 1000–8000 l/h [6]. Windmills however can operate only in locations with medium wind regimes and with no surrounding obstacles such as buildings or trees. The system costs are also very high and are therefore unaffordable to many individual users. The cost of setting up a water-pumping windmill varies from about $1340 to about $3600 [6]. The Ministry of Non-Conventional Energy Sources provides for the ex-works of the cost of setting up the system, and even higher subsidies for unelectrified islands.

Small wind electric generators (aerogenerators) can be installed as stand-alone systems or along with solar photovoltaic systems, to form a solar hybrid system for decentralized power generation suitable for unelectrified areas. The optimum wind speed for aerogenerators is at about 40–45 km/h [6]. Batteries can be charged and used during non-windy periods. The cost of these systems is around $4000–$5000/kW and they require maintenance work of about $40per kW per annum [6].

Wind-solar based hybrid systems produce mutually supplemented power, thus offering reliable and cost-effective decentralized electric supply. Batteries can be charged for use as when required. The cost of the system varies from $5000–$7200/kW [6]. Installation costs are about $205, while maintenance and repair costs are about $60 per kW per annum [6]. The MNES provides subsidies for community use as well as higher subsidies for non-electrified islands. These systems are installed through nodal agencies using central subsidy and manufacturing bases have been developed. State nodal agencies are in charge of providing repair/service facilities through the respective manufacturers.

6.5. Hydro power

India is endowed with hydro resources which are both viable and economically exploitable. In fact, hydro power is the second highest contributor of the energy consumed in the power sector. Large hydro power projects are being utilized for power production, and account for most of the energy consumed which comes from renewable sources. The hydro potential has been assessed to be about 84,000 MW, at 60% load factor [13]. In addition to this, 6780 MW of installed capacity from small, mini and micro-hydel schemes have been assessed, and 94,000 MW of installed capacity have been assessed for pumped storage schemes [15]. However, only 19.9% of the potential has been harnessed so far.

As hydro power has been tapped and used for grid purposes, small hydro power will be focussed on in this discussion, as small hydro power has small scale applications which would benefit the energy deprived. Small scale hydro power (SHP) projects are hydro power projects with a station capacity of up to 25 MW each. These can be set up on rivers, canals or at dams and are flexible in terms of installation and operation. The technologies and manufacturing base is indigenous in SHP projects. Small Hydro Power project equipment is being manufactured in India. According to the Ministry of New and Renewable Energy Sources, 11 small hydro power equipment manufacturers currently operate in India. It is also environment friendly as it causes little or no submergence, minimal deforestation and minimal impact on flora, fauna and bio diversity. These projects are in fact even compatible with use of water used for irrigation and even drinking water.

The cost of SHP projects depends on where they are set up, i.e. the location and the site's topography. The cost of the civil works and the equipment usually determine the cost of the project. They normally cost between $1 million to about $1.4 million per MW [6]. Pay-back period of these projects is usually 5–7 years and this depends on the capacity utilization factor.

The Ministry of Non-Conventional Energy Sources has so far installed 523 SHP projects with an aggregate installed capacity of 1705 MW, and have 205 SHP projects with an aggregate capacity of 479 MW under implementation. The SHP sector is increasing its competitiveness with other alternatives, through increase in capacity by an average increase of 100 MW per year, and through reduction in the gestation period and capital cost. Databases containing potential SHP sites have been created and a programme involving subsidies is being planned for encouraging development of SHP plans in states across India. In order to be eligible for subsidies, standards for quality have been put in to place.

States in India have put policies such as low interest rate loans in place, in order to attract private sector entrepreneurs to set up SHP projects. Tariffs are being determined by the state electricity regulatory commissions keeping the interest of stakeholders, developers and the Ministry of New and Renewable Energy Sources in mind. Several leading financial institutions have started financing SHP projects, thereby providing stable and secure financing options.

Water mills are an example of converting the energy of water into useful mechanical energy. They have been used in north India for applications such as grain grinding and oil extraction. These normally have low conversion efficiency and improved systems have been developed for electricity generation. The Ministry of New and Renewable Energy Sources have a scheme for water mill development through associations, cooperative societies, NGO's, local bodies and state nodal agencies. The scheme subsidises up to 75% of the actual cost if lower than the ceilings [6]. These have been effective in remote and rural areas with suitable topography in states such as Uttaranchal in North India.

6.6. Biogas

India is currently the fifth largest consumer of biogas. The biogas derived from animal waste in India is mainly from cow dung. The estimated potential of household biogas plants derived from animal waste in India is 12 million plants. Under the National Biogas programme over 3.7 million biogas plants of 1–6 m^3 had been installed till December 2004 [6]. Since then, the Ministry of New and Renewable Energy Sources has established larger units in sev-

eral villages, farms and cattle houses. An estimate of 3.5 million m^3 per day of biogas production is provided by the Ministry of New and Renewable Energy Sources. This is equivalent to a daily supply of about 2.2 million m^3 of natural gas.

Biogas plants in India provide gas for cooking, lighting and power generation. Biogas is used with specially designed burners for cooking and plants of 2 m^3 capacity are sufficient for families with four to five members. Gas lamps are fuelled by biomass and for a 60 W lamp, 0.13 m^3 of biogas is required per hour. It can also be used to generate mechanical and electrical power by replacing 75% of the diesel used in dual-fuel engines with it. Efforts are being made to generate electricity from biogas in a decentralized mode by means of small-capacity engines. Thus, standardized models of biogas plants suitable for even households are available. For family-type biogas plants the fixed-dome and floating-drum plants of 1–4 m^3 capacity is usually used [6].

In India, not only is biogas plant related technology and infrastructure being developed, but training and deployment of skilled manpower for plant construction and maintenance has also been taking place. The plants also take care of treatment of industrial and urban waste to a large extent, as the technology of using anaerobic digestion to treat these wastes and produce biogas has been successful. The biogas slurry is rich in a water-soluble form of nitrogen and hence can be used as organic manure. It is also rich in bacteria and can therefore be used for composting along with biomass. Hence, these plants not only provide a more efficient energy source, they also provide employment to a large number of people in the rural areas and provide solutions to environmental problems, such as waste and manure handling, water pollution and carbon monoxide emission.

The lifespan of biogas plants in India can be estimated to be about 10 years. Based on the life-cycle analysis, the estimated cost of generation of 1 m^3 of biogas is 6 cents and this is said to be more cost-effective than the cost of diesel and kerosene when comparing energy values [6]. The Ministry of New and Renewable Energy Sources has also estimated that the construction of 1 million biogas plants generates about 30 million man-days of employment for skilled and unskilled workers and 1.2 million tonnes of organic manure per year. It also leads to abatement of greenhouse gas emissions through anaerobic digestion of cow dung and effective utilization of biogas.

Financial assistance for construction and maintenance of biogas plants, development of skilled manpower, training for use and maintenance, awareness creation, and support to implementing agencies and technical centres for implementation are provided by the Ministry of New and Renewable Energy. The National Biogas Programme in India provides various central subsidies for setting up biogas plants and the amount depends on the users and the area. Thus promoting the set-up of these plants in remote and under developed areas and for users who do not have access to electricity, as well as those who have greater development and energy needs. The Government of India also provides repair and servicing facilities to support the operation of these plants. The state governments have also implemented programmes targeted at implementation and training support. They help regularly organise training of workforce in the construction, maintenance and use of the biogas plants. The training centres also provide technical training and publicity support for the National Biogas programme.

7. Results

Having looked at the household energy trends we see that there is still a great dependence on solid fuels. The percentage of residential energy needs met by solid fuels is only 80% and as these fuels are highly inefficient, polluting and create health burden, cleaner and more efficient alternatives must be provided. Also, there has been an increase in the overall biomass consumption even though dependence on it in households has decreased. A drastic difference is observed in the trends between urban and rural consumption reflects difference in preferences of fuels is due to unequal development and differences in the availability and affordability of fuels. This is also supported by the fact that the population in rural areas that earns as much income as those in the urban areas, still consume a greater percentage of solid fuels, due to lack of accessibility to other alternatives. Differences in consumption patterns varying geographically between states according to availability of resources as well as differences in the extent of development have also been observed. All these factors imply that the Government of India must play a significant role and putting relevant policies in place to promote the use of grid electricity over solid fuels, as well as being more proactive by providing more energy source alternatives along with the pace of the growing population and its needs. Also, the policies must be targeted towards rural areas and the main consumers of the solid fuels. Subsidies should not only be determined by what resources are easily available, but also keeping in mind the impacts and indirect costs, such as cost to the environment, of the fuels in mind.

India encounters the problem of a negative balance in overall energy consumption and production, and the growing population adds to the problem. It can be seen that the majority of electricity produced comes from the use of coal while only a small percentage from renewable energy sources which do not include large scale hydro projects. The commitment of the Government is to provide the entire population with electricity by 2012, to increase per capita availability of electricity from its current figure of around 380–421 kWh/capita [16] to over 1000 kWh/capita by 2012 [6], as well as the achievement of the development goals. Each of these goals has an associated energy cost and entails an increase in the requirements of energy. In order to stick by the commitment made by the Government through the ratification of the Kyoto protocol, sustainable options must be focussed on. The Government of India has taken steps towards this by putting much needed electricity policies in place and by focussing on renewable energy technologies.

For remote villages which are not connected to a grid, decentralized application of renewable energy sources provide a suitable alternative. The Intergovernmental Panel on Climate Change (IPCC) report findings which also show that it is the right time to look at alternative energies for rural energy supply. Successful rural electrification programmes have shown that a sustained renewable energy market can develop quickly and efficiently through the right combination of institutional and financial regulations and if adequate energy policies are adopted. The Government's electricity policies display their intention of overcoming hindrances to electrification, especially to rural electrification, but some issues however are still not resolved and there is scope for further improvement.

The Government's measures such as the setting up of the Ministry of New and Renewable Energy Sources show their intent of having renewable energy sources play an important role in the further electrification of the country, and in the eradication of energy poverty. We notice how the potential of renewable energy sources have not been tapped in India. This shows a great scope for improvement, provided the right encouragement is provided by the Government.

Solar thermal energy is a cost effective and reliable form of energy and it has several household applications relevant to rural areas, where access to modern energy fuels and services is limited. The photovoltaic route in India has also been well established. Even the manufacture of photovoltaic cells takes place in India. The Government's assistance in terms of setting standards and setting up testing facilities for solar cells, PV modules and systems helps

encourage high quality in the photovoltaic manufacturing sector in India. The targeting of categories of users for the solar home systems by the Government is useful in providing benefits for those who need it.

For wind energy there are greater limitations as the resources are not evenly distributed. For the small scale wind projects, there are obstacles which cannot be helped, such as need for perfect isolated locations with the current wind speeds. These limitations do not make them a universally ideal solution to the need for rural electrification. However, India has not tapped its full wind energy potential and through the infrastructure and programmes set up, wind energy sources will provide a lot more benefits in the future. By taking care of maintenance and providing installation subsidies, the Government of India is trying to make it attractive. State involvement assists in providing the required decentralized support to systems which provide rural electrification.

Hydro projects have excellent efficiency, low maintenance costs and low costs of generation. Small scale hydro projects have the advantage of using indigenous technology which is manufactured in India and they cause a minimal environmental damage. The technology for these systems is rapidly improving and becoming more and more competitive. The Government's support, through subsidies and setting up of databases, is encouraging the development of these systems and making them more affordable. Financial assistance through loans and subsidies are also helping the setting up of these systems. The involvement of state nodal agencies thereby provides the decentralized support required.

The use of biogas in households also saves women and children from exposure to indoor pollution, and the time as well as the effort they spend in collecting firewood and cooking with inefficient fuel sources. Thus this technology provides various environment-related advantages and social related advantages, while providing energy solutions to energy deprived rural areas. Financial assistance for construction and maintenance of biogas plants, development of skilled manpower, training for use and maintenance, awareness creation, and support to implementing agencies and technical centres for implementation are provided by the Ministry of New and Renewable Energy. Therefore the Government is not just providing financial support and technical assistance for biogas plants, they are also enhancing development by providing job opportunities to those living in rural areas. They are providing training as well as employment for people from the rural areas, thereby bringing about development in more than one way.

Although renewable energy technologies might require low cost or free fuel, they incur high upfront capital costs. The cost of electricity produced (UNDP 2004) by solar photovoltaic route is about 25–160 cents/kWh, by solar thermal route around 12–34 cents/kWh [16]. In India in fact, the cost of grid-interactive power plant produced electricity is around 31 cents/kWh and from stand alone power plants it is more expensive [6]. Cost of electricity production for wind energy is 4–8 cents/kWh and for small hydro energy plants is 2–12 cents/kWh (UNDP 2004) [16]. Whereas based on life cycle analysis, the cost estimated for the generation of biogas from a family-type plant is 6 cents. By conventional coal electricity generation is about 4 cents/kWh [17]. We see that in terms of costs of electricity generation, conventional coal technology is much cheaper in comparison to renewable energy source technologies. As the customers of electricity in rural areas are from lower income groups and private parties will not invest unless it is commercially viable, the burden of these costs must be borne by the Government.

8. Conclusions

As a considerable percentage of the world's poor reside in India, the issue of sustainable development is a key concern. It has been established that access to clean energy enhances development by providing several opportunities and improving the quality of life. Most of India's poor live in the rural area and hence a greater focus must be placed on the access of energy sources to these regions. By announcing their development goals and by announcing the goals of providing electricity to the entire population by 2012, the Government of India is committing itself to development and reduction of poverty.

By making electric power accessible to the whole population by 2012, the Indian Government is ensuring the eradication of energy poverty. Increasing the reliability of quality of power and its efficiency at reasonable rates helps target the needs of the people of lower income groups. This helps ensure proper electrification for the regions which although are declared electrified, have poor services and cannot reap the benefits of electricity. An increase in per capita consumption, which is stated as a policy, does not imply equitable distribution but it does imply a greater level of development. Making electric power commercially viable will decrease dependence on sponsors and make it profitable for private parties to invest in thereby reducing the dependence on sponsors. The involvement of private parties in fact will reduce maintenance costs, reduce overuse and also maximise benefits from these systems. The protection of the consumers' interests ensures that these keep in mind the energy deprived and prevent them from being exploited by private investors who enter the energy market. Regular preparation and publication of policy and tariffs will help establish fixed guidelines for the sector, to avoid ambiguity and promote private investment. National policy for permitting standalone systems including renewable system for rural areas implies making it easier for private investment to set up these projects and promoting such projects in general. The intended determination of tariffs based on the generation and co-generation from renewable sources show how there will be an added advantage for renewable based technologies, hence promoting investment in them. Establishing the responsibilities of the state government, addresses the decentralized problem solving which is required to deal with issues related to rural electrification, which are decentralized in nature themselves. The Indian Government has also established several programmes and institutions to increase reliability in this sector and makes it purchase and payment of these systems easier. The Government has also addressed the problems of maintenance and monitoring by taking up this responsibility through its various institutions. This shares the burden with the involved parties and also builds confidence in the systems. The policies of the Government however do not explicitly address the current electricity subsidies. The subsidised electricity does not target the increase in energy access by energy deprived rural households, and in fact it benefits richer urban households who have greater access to more modern energy technologies.

A large number of programmes and initiatives have been carried out by the Government of India. However, they have set unrealistic targets in terms of their development goals and reduction in energy poverty. To achieve these targets, the initiatives taken so far are insufficient. For the achievement of these targets through sustainable means, renewable energy technologies must be encouraged to a further extent. The Indian Government has made an ambitious start. However, the different levels of government, local, state and national, need to increase their efforts to a much greater extent in order to achieve significant results.

References

[1] United Nations. Human Development Report; 1997.
[2] International Energy Agency. IEA Analysis World Energy Outlook. Paris: International Energy Agency; 2009.
[3] Modi V, Mcdade S, Lallement D, Saghir J. Energy Services for the Millennium Development Goals. New York: Energy Sector Management Assistance Pro-

gramme, United Nations Development Programme, UN Millennium Project, and World Bank; 2006.
[4] Government of India. IEA Poverty estimated for 2004-2005 [WWW] Government of India Press Information Bureau; 2007. Available from: http://www.planningcommission.gov.in/news/prmar07.pdf[accessed 22/02/2010].
[5] United Nations Development Programme (UNDP). India Human Development Goals [WWW] Available from: http://www.undp.org.in/index.php?option=com[accessed on 12/01/2009].
[6] Government of India (n.d.) Renewable Energy Booklets [WWW] Ministry of New and Renewable Energy. Available from: http://www.indiaenvironmentportal.org.in/[accessed 15/07/2009].
[7] Global Network on Energy for Sustainable Development (GNESD) Poverty Reduction-Can Renewable Energy make a real contribution?: GNESD publication.
[8] Clancy JS, Skutsch M, Batchelor S (n.d.). The Gender-Energy-Poverty Nexus, DFID, Project CNTR998521.
[9] World Coal Institute (n.d.) Country Profiles: India [WWW] Available from: http://www.worldcoal.org/pages/content/index.asp?PageID=402 [accessed on 22/12/2008].
[10] Pachauri S, Jiang L. The household energy transition in India and China. Energy Policy 2008;36:4022–35.
[11] Urmme T, Harries D, Schlapfer A. Issues related to rural electrification using renewable energy in developing countries of Asia and Pacific. Renewable Energy 2008;34:354–7.
[12] Rodríguez Monroy C, San Segundo Hernández A. Strengthening financial innovation in energy supply projects for rural exploitations in developing countries. Renewable and Sustainable Energy Reviews 2008;12:1928–43.
[13] GENI. Overview of Renewable Potential of India: Global Energy Network Institute Publication; 2006.
[14] Duflo E. Indoor air pollution, health and economic well-being. S.A.P.I.EN.S, 1.1; 2008. [WWW] Available since 19 December 2008 from: http://sapiens.revues.org/index130.html[accessed 22/12/2008].
[15] NHPC Limited (n.d.) Hydro Potential [WWW] Available from: http://www.nhpcindia.com/English/Scripts/Hydro_Potential.aspx[accessed on 22/12/2008].
[16] IAEA (n.d.) Energy and Environment Data Reference Bank: Republic of India [WWW] International Atomic Energy Agency. Available from: http://www.iaea.org/inisnkm/nkm/aws/eedrb/data/IN-elcc.html[accessed 22/12/2008].
[17] UNDP. World Energy Assessment-Overview: 2004 Update: United Nations Development Programme, United Nations Department of Economic and Social Affairs and World Energy Council; 2004.